Private Incentives for Sustainable Agriculture: Principals and Evidence for Sustainable Agricultural Change

David J. Pannell[a], Philip G. Pardey[b], and Terrence M. Hurley[b]

[a]UWA School of Agriculture and Environment, The University of Western Australia, Crawley, WA 6009, Australia
[b]Department of Applied Economics, University of Minnesota, St. Paul, MN 55108, USA.

*E-mail address: david.pannell@uwa.edu.au

9 July 2020
Working Paper 2002
UWA Agricultural and Resource Economics
http://www.are.uwa.edu.au

Citation: Pannell, D.J, Pardey, P.G., and Hurley, T.M. (2020) *Private Incentives for Sustainable Agriculture: Principals and Evidence for Sustainable Agricultural Change*, Working Paper 2002, Agricultural and Resource Economics, The University of Western Australia, Crawley, Australia.

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Key words: agriculture, economics, sustainability, adoption, incentives

JEL classifications: Q1, Q2, Q5

Research categories:

- Agricultural and Food Policy
- Environmental Economics and Policy
- Farm Management
- Land Economics/Use
- Production Economics

David Pannell is Professor of Agricultural and Resource Economics in the School of Agriculture and Environment and Director of the Centre for Environmental Economics and Policy at the University of Western Australia. Philip Pardey is Professor of Applied Economics and Director of the International Science and Technology Practice and Policy (InSTePP) center at the University of Minnesota, and Terrence Hurley is the Austin A. Dowell Professor of Applied Economics at the University of Minnesota.
The research leading to this paper was funded by PepsiCo Inc. The content of this paper is the sole responsibility of the authors.

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Over the past several decades increasing consumer and public policy attention has been paid to the environmental impacts of agricultural production. Much of the concern has centered on water pollution, soil erosion, climate change and loss of biodiversity and the potential for agriculture to deliver benefits in these areas (OECD, 2015). These concerns have manifested themselves in a host of public policy responses, including land set-aside and stewardship programs for the provision of ecosystem services, various restrictions on the use of farm chemicals (including pesticides and herbicides), and a raft of other public policy instruments intended to spur farmers into adopting more "sustainable," environmentally-friendly, production practices.

Of late, these public regulations have been augmented by a host of private initiatives. For food and agriculture, these private initiatives often take the form of corporate social responsibility or sustainability targets set by food retailers, processors and others in the food supply chain.[1] Meeting these private targets can imply substantial and asymmetrically borne costs and benefits, with major implications for the incentives to adopt eco-friendly practices. For example, benefits can accrue to consumer-facing retailers by way of improved market shares and profitability arising from selling sustainably branded food produce that realize a price premium. Meanwhile, substantial shares of the cost of compliance may fall on those further down the value chain. Those farmers selling segregated, sometimes farm branded (local, and often perishable) produce into food supply chains may benefit from enhanced farm-gate prices. But others selling non-segregated bulk commodity (grain or livestock) produce are more vulnerable, possibly bearing the farm-level costs of compliance with little or no ability to realize a higher price for their product.

[1] Notably, in some markets (for example the United States), the pre- and post-farm parts of these supply chains are becoming increasingly concentrated as firms in each of the input supply, food processing and food retailing segments of this chain consolidate via on-going mergers and acquisitions (see, for example, MacDonald 2017). U.S. farms are consolidating too, but are still nowhere near the concentration ratios of the agribusiness sectors, where typically four firms account for more than half of total firm sales within each sector.

This can give rise to a situation where the incentives to adopt more sustainable food chain practices are weakest on the farm where the farm-level cost of change may exceed the farm-level benefits, even though the social benefits may be large. The inability of many farmers to capture sufficient value from adopting more sustainable production practices may partly explain the limited voluntary (or market-driven) uptake of many sustainable production practices to date. For example, Wade et al. (2015) reported that in 2010 and 2011, cover crops were used on less than 2 percent of land used in the U.S. for its four main crops (corn, wheat, cotton, and soybean). On only 24 percent of U.S. cotton acres and 6 percent of corn did farmers combine all four nutrient management practices that are recommended to reduce nutrient runoff, namely (1) no fertilizer application in the fall, (2) some application after planting, (3) nitrogen application at rates below a "benchmark," and (4) fertilizers incorporated or injected below the soil surface.

By contrast, zero-till (or no-till) is a practice that generates benefits for both farmers and the environment. Thanks to the private benefits for farmers, around 40 percent of U.S. corn, soybean, wheat, and cotton crops, totaling 89 million acres per year, were sown using zero-till or strip-till in 2010 and 2011. This use of zero-till, though motivated by private benefits, generates a variety of public benefits, including reduced sediment and phosphorus in rivers, and increased sequestration of carbon in agricultural soils.

In this series of reports, we discuss the opportunities for private incentives to drive greater adoption of new or changed farming practices that generate public benefits.[2] This includes private incentives to farmers, and private incentives to other participants in the agricultural supply chain. We blend theory and practice with an eye to both the economic and environmental risks and rewards involved.

[2] Our approach, which puts the (often highly localized) private decisions of farmers (and others) front and center, contrasts with the preponderance of the agronomic (e.g., McLellan et al. 2015) and economic (e.g., Nelson et al. 2009) literature, which typically approaches the problem from a high-level "social planner" perspective.

1. Understanding Farmers' Decisions to Change Their Practices

Initiatives to influence farmers can benefit greatly from the extensive body of research on the adoption or non-adoption of agricultural practices, as reviewed by Feder et al. (1985), Feder and Umali (1993), Lindner (1987), Pannell et al. (2006), Knowler and Bradshaw (2007) and Pannell and Vanclay (2011). This research has quantified the speed and extent of uptake of new practices by farmers, identified drivers of and barriers to adoption, and developed conceptual frameworks to understand the adoption process.

Adoption as a Learning Process

Adoption is a learning process with two distinct aspects. One is the collection, integration, and evaluation of new information to allow better decisions about an innovation. Early in the process, the landholder's uncertainty about the innovation (e.g., about its profitability relative to present farm practices) is high, and the quality of decision making may be low. As the process continues, if it proceeds at all, uncertainty is reduced and better decisions can be made (Barham et al. 2015; Marra et al. 2003; Abadi Ghadim and Pannell 1999; Lindner at al. 1979). At least for relatively simple innovations, a landholder's probability of making a good decision – one that best advances their goals – increases over time with increasing knowledge of, and perhaps experience with, the practice.

The other aspect of learning is improvement in the landholder's skills in applying the innovation to their own situation (Tsur et al*.* 1990). Most farming innovations require a certain level of knowledge and skill to apply them in practice and there can be a wealth of choices in the method of implementation (e.g. timing, sequencing, intensity, scale). Through learning-by-doing, as well as by reading, listening and watching, the necessary skills can be established and enhanced.

The dynamic learning process has been broken down into stages or phases in a number of different (though similar) ways. One typical description of the sequence follows.

i. Awareness of the problem or opportunity
ii. Non-trial evaluation
iii. Trial evaluation

iv. Adoption
v. Review and modification
vi. Non-adoption or dis-adoption

Typically, adoption is not an all-or-nothing decision–there is a grey area between small-scale trialing and the eventual scale of adoption (Duncan 1969). Adoption is often a continuous process and may occur in a gradual or stepwise manner, sometimes ending in only partial adoption (Byerlee and Hesse de Polanco 1986). Landholders often change and modify the practice or technology to adapt it to their own circumstances. Indeed, such adaptation is often an important outcome of the trialing process.

Prior to trialing, the landholder's assessment of a technology or practice relies strongly on information from outsiders. At this stage, social and information networks are important influences on the decision to proceed to trial, but after trialing has commenced, personal experience is likely to be the main influence on further decisions (Dong and Saha 1998; Marsh et al. 2000). There is no guarantee that a landholder's subjective beliefs will ultimately lead them to a final decision that is actually the one most likely to best achieve their goals. Reasons include that some practices are relatively complex and/or not clearly observable.

Social and Economic Factors that Influence Adoption

Phillips (1985) found that a typical dairy farmer may embark on up to 30 learning projects in one year. A farmer has limited learning time, and each project must compete with the others for that limited time. A decision of minor importance will receive minimal information time, sufficient to achieve an acceptable solution, which is not necessarily the best possible solution. For more important decisions, the dairy farmers in Phillips' (1985) study sought information from up to 40 people.

Although pursuit of profit is clearly an important motivation for many (and probably most) farmers, it is not the only objective pursued in agriculture. Rather, the goals of farmers (and their families) are heterogeneous, and can include the following: (i) material wealth and financial security; (ii) environmental protection and enhancement (beyond that related to personal financial gain); (iii) social approval and acceptance; (iv) personal integrity and high ethical standards; and (v) balance of work and lifestyle. Of course, the first of these goals is particularly important to most farmers, so insights into the farm-level economics of new practices are outlined in the next section.

When adoption is viewed as a social process, it becomes clear that one should expect adoption behavior to be influenced by the personality of the decision maker, their social networks, personal circumstances, and family situation. It seems that in the empirical literature every measurable characteristic of farms and farmers has been found to be statistically related to some measure of adoption of some innovation (e.g., Rogers 2003). This reflects the heterogeneity of adoption study settings, the very large size of the literature, and the variable quality of empirical studies (as noted, for example, by Lindner 1987).

A widely discussed and long-standing concept is categorisation of people across a spectrum from innovators to laggards (Rogers 2003). People do indeed have personal characteristics that influence their adoption decisions fairly consistently. However, the concept of adopter categories suggests that innovativeness is a personal characteristic that people apply equally to every adoption decision that they make. This is not so. People who adopt one innovation early are not necessarily early adopters of all innovations. It may be that the innovation in question is particularly attractive in their individual circumstances, whereas the same decision maker when considering a different innovation that is less attractive to them than it is to others may behave as a slow adopter or non-adopter.

Several aspects of the linkages between landholders and others may affect the adoption decision:

i. The existence and strength of farmers' social networks and local organizations (e.g., Sobels et al. 2001) and membership of organizations such as catchment groups;
ii. The physical proximity of other adopters (e.g., Ruttan 1996);
iii. The physical distance of the property from sources of information about the innovation is important (e.g., Lindner et al. 1982);

iv. A history of respectful relationships between landholders and advocates for the innovation, including scientists, extension agents, other landholders, and private companies (e.g., Marshall 2004);
v. Extension, promotion and marketing programs by government workers and/or the private sector (e.g., Marsh et al. 2000).

Demographic and situational variables are judged to be important because they will influence the goals of the landholder and potentially influence the capacity to adopt an innovation. Some examples of these variables are listed below.

i. Lack of financial viability would be expected to inhibit adoption of innovations by reducing the capacity to adopt, rather than the benefits of adopting (Cary et al. 2001).
ii. Access to and reliance on off-property income may increase financial security but also may decrease the tendency to adopt some practices that would involve greater management demands (Kebede 1992).
iii. Property size is often, but not always, related to innovation adoption – larger areas tend to increase the overall benefits of adoption of beneficial innovations and so increase the likelihood of adoption.
iv. The evidence of a relationship between adoption and age, stage of life or experience is mixed. The most extensive meta-review of socio-economic factors influencing adoption found both positive and negative relationships between age and adoption (Rogers 2003).
v. There can sometimes be relationships between education and the adoption of conservation practices (e.g., Feder et al. 1985), although the evidence is again somewhat mixed (e.g., Marsh et al. 2006).
vi. The reason for holding land (e.g., agricultural production *vis a vis* lifestyle) can influence adoption decisions.

Characteristics of the New Practice that Influence Farm-Level Adoption

There are two broad categories of characteristics of a technology or practice that drive its adoption or non-adoption: its “relative advantage” and its “trialability.”

Relative advantage means “the degree to which an innovation is perceived as being better than the idea [or practice] it supersedes” (Rogers 2003, p. 229). Relative advantage depends on the farmer’s unique set of goals and the biophysical, economic and social context where the innovation will be used. Relative advantage is the decisive factor determining the ultimate level of adoption of most innovations in the long run.

Relative advantage depends on a range of economic, social and environmental factors, such as:

i. The short-term input costs, yields and output prices of the innovation or of other activities that it affects
ii. The innovation’s impact on profits in the medium-to-long term
iii. The innovation’s impacts on other parts of the farm system within which it will be embedded
iv. Adjustment costs involved in adopting the innovation
v. The innovation’s impacts on the riskiness of production
vi. The innovation’s compatibility with a landholder’s existing set of technologies, practices, and resources
vii. The innovation’s complexity
viii. Government policies
ix. The cost or profitability of the traditional practice that the innovation would replace
x. The compatibility of a practice with existing beliefs and values
xi. The impact of the innovation on the family lifestyle
xii. Self-image and brand loyalty
xiii. The perceived environmental credibility of the practice

The crucial role of relative advantage as a driver of adoption, and the importance of profit as one of the drivers for most farmers, have strong implications for conservation practices. Those conservation practices that are not profitable at the farm level will tend to be adopted only by farmers with stronger conservation goals. Conservation land uses that require adoption at large scale to generate conservation benefits will probably not be adopted sufficiently if they are perceived to be less profitable than the land uses they replace unless a policy or program provides sufficient incentives through payments or penalties.

Some conservation-related practices have been adopted widely without government financial support or regulation, notably zero-tillage (e.g., Fulton 2010; Horowitz et al. 2010; Llewellyn et al. 2012). The explanation is that zero-tillage makes substantial contributions to the adopting farmers' economic goals in the medium term, such that it is worth overcoming the various barriers to adoption that arise. This highlights that the relative advantage that drives adoption of a conservation practice may not necessarily relate to the environment. Indeed, environmental benefits can often be most readily achieved by developing conservation practices that provide a *commercial* advantage to farmers.

In contrast, the scale of voluntary adoption of many conservation practices has been lower than the levels preferred by environmental advocates. For example, Wade et al. (2015) found that only 6 percent of corn acres and 24 percent of cotton acres in the United States meet four criteria for the sustainable management of nitrogen: no Fall application, overall application rate at or below the benchmark, at least some nitrogen applied after planting, and fertilizer incorporated or injected below the soil surface.

There are many potential barriers that may contribute to this result, and different ones are more or less decisive in different cases. Commonly observed factors that tend to reduce the relative advantage of at least some conservation practices include:

i. High establishment costs
ii. Low profitability once the practice is established
iii. Long time lags between establishment and conservation benefits
iv. Riskiness of the practice and uncertainty about its (economic and environmental) benefits
v. Complexity of the practice
vi. Spillovers from neighbors being perceived as the source of environmental degradation, such that farmers feel disempowered.

Some characteristics of a new practice affect how easily a farmer can learn about its performance and optimal management – in other words, the trialability of the practice. Trialability does not merely refer to the ease of physically establishing a trial, but encompasses factors that influence the ability to learn from a trial, such as the complexity of the issue being addressed.

Trialing an innovation provides information that reduces uncertainty about the relative advantage of the practice. Thus, trialing is important because it can increase the probability of the landholder making a correct decision, not least given the spatial variability in the outcomes from a given agricultural practice. Trialing also provides an opportunity for the landholder to learn the skills needed to apply the innovation. The small-scale nature of a trial allows the landholder to avoid the risk of large financial costs if the practice turns out to be uneconomic or fails due to inexperience.

The trialability of a practice is affected by a number of factors, including those listed below. Note that several of these factors were also listed as influences on relative advantage.

i. The ability to implement the new practice on a small scale, or to use a sub-component out of a package of practices (this ability is positively related to adoption) (Leathers and Smale 1992);
ii. The observability of results from a trial (positive);
iii. The time lag between adoption and eventual benefits (negative);
iv. The complexity of an innovation (negative);
v. The cost of undertaking a trial (negative);
vi. Risks of trial failure (e.g., due to threats such as drought, diseases, pests, and establishment failure) (negative);
vii. Quality of trial implementation (positive);
viii. Similarity in behavior of the innovation to a familiar practice (positive), allowing the landholder to extrapolate more readily from a small number of observations of the new practice (Abadi Ghadim et al. 2005);

Unless the challenges in trialing a new practice are so severe that they entirely block the adoption of a practice, the main influence of trialability is on the speed of adoption of the practice, rather than on its final level of adoption.

2. Heterogeneity in Farms and Farmers

There is heterogeneity among farmers on all the socio-economic dimensions outlined above: their business and personal goals, their networks, their relationship with scientists and extension agents, their off-farm income, and so on. The physical aspects of farms are also heterogeneous, in terms of farm area, soil types, distance from market, climate, topography, distance from water bodies, depth to groundwater, existing soil carbon levels, and so on. For these reasons, decisions about the adoption of a new practice vary from farm to farm, often for sound and sensible reasons. It is rare for a new practice to be used in the same way and over the entire areas of all farms. Instead, a new practice is almost inevitably used by a sub-set of farmers (for whom it works best) and over a sub-set of their land areas (those areas where it works best). In many cases, the way a practice is implemented varies on different farms. For example, a cover crop may be plowed in to enhance soil fertility or harvested for livestock feed.

This heterogeneity has two important implications. Firstly, it provides a reality check on what can realistically be expected from an initiative to encourage adoption of a new practice. Irrespective of what messages farmers are given, they will make their own individual decisions about whether, how much, and in what way to use the practice. Information can help them to make better decisions (better from their own perspective), or to make them more rapidly, but there are fundamental realities about the farmer's goals and circumstances that largely determine the ultimate extent of adoption of the practice.

Secondly, there may be benefits from targeting an initiative to a sub-set of farmers who are most likely to adopt the new practice at large scale (Morrison et al. 2012). Targeting may involve the selection of particular regions, or selection of particular farmers within a region. Such targeting may be able to increase the return on effort and investment in the initiative. This pre-supposes that it is possible to identify which regions or which farmers are more likely to adopt. Moreover, regions or farms not only vary in their propensity to adopt, but once the changed practice is adopted they may also vary in the (off-farm, or interregional, i.e., external) environmental consequences of the changed practice. Thus the process of identifying likely adopters, and assessing the external environmental consequences of adoption, requires information and so comes at a cost. It is an open question whether the overall benefits of targeting outweigh this cost in particular cases.

3. Farm-level Economics of Practice Change

The importance of the profit motivation for farmers means that it is worth considering farm-level economics in more detail. One issue is the general level of profitability of a farm. If the farmer is struggling economically (e.g., through drought or low product prices), the capacity to invest time and resources in trialing and adopting a new practice is likely to be diminished, unless the new practice is perceived to be one that could solve the economic problems facing the farmer.

More important than this general economic consideration is the specific economic performance of the new practice relative to the practice(s) that it would replace. The "relative to …" aspect is critical. If adoption of the new practice requires the farmer to give up an existing profitable practice (e.g., the new practice is a new crop type that would replace an existing crop type), then the "opportunity cost" of giving up the existing practice needs to be considered as a cost of adopting the new practice.

The measure of economic performance that is relevant to a farmer may vary from very short term to very long term, depending on the farmer's circumstances and goals.

Returning to the issue of heterogeneity, Figure 1a illustrates a potential relationship between the proportion of adoption (e.g., the proportion of land in a region on which the practice is used) and the marginal cost of adopting the practice. In this figure, the land is ranked (left to right) from lowest to highest marginal cost (to the farmer) of adoption. This graph illustrates a situation where there is a small negative cost of adoption (i.e., a small private benefit) on about 25 percent of the land, and an increasingly large cost of adoption to the farmer as the level of adoption rises towards 100 percent.

[Figure 1: *The Private Costs of Adoption*]

This broad pattern is likely to be realistic for some environmental practices. In such cases, adoption at low percentages (up to 25 percent in this figure) generates some private benefit for the farmers, but the level of benefits is low so that they provide little incentive to encourage uptake. The economics are not actually a barrier to adoption at these levels, so it is relatively feasible for an initiative to generate some change.

If the farmers in this example are somewhat altruistic and are willing to bear some private costs to provide public benefits (e.g., Chouinard et al. 2008), it may be possible to persuade them to adopt the practice on up to say 50 percent of land in the region. Beyond that level of adoption, costs of adoption rise rapidly so additional adoption is unlikely to occur.

The general shape of the graphs in Figure 1, with increasing marginal costs as adoption increases, would be common for many environmental practices. However, even if the exact shape holds, the cost intercept will likely vary between practices and between regions. Figure 1b shows an example where the cost intercept is more negative. In this example, there is a much stronger profit motivation for adoption of the practice, up to around 65 percent of the relevant area. In this case, we would expect voluntary adoption to occur up to that level even in the absence of a policy or program to promote this practice. Given the steepness of the cost curve beyond about 70 percent, achieving higher levels of adoption would be very challenging and costly. In a scenario like this, it seems unlikely that an initiative to promote this practice would be highly beneficial. At best, the initiative might be expected to increase the speed of adoption, but probably not the final extent of adoption. In Figure 1c, the cost intercept is well above zero. In other words, even low levels of adoption come at a high cost. In this situation, achieving any adoption will be costly and difficult. Adoption is only likely to occur in response to high incentive payments to farmers, or as a result of strong and well-enforced environmental regulations.

These three examples further highlight the potential for prioritization and targeting of effort. An initiative to promote the adoption of an environmental practice is far more likely to generate benefits in cases like Figure 1a than in cases like Figure 1b or Figure 1c.

Flat Payoff Functions

For decisions about the rate of an agricultural input, it is very common to observe that there is a “flat payoff function.” In other words, either side of the optimal input rate, there is a wide range of input levels that provide very similar levels of profit (or another measure of payoff) (Pannell 2006). The width and flatness of the profit plateau vary, but the presence of a profit plateau is almost universal in economic production models with continuous decision variables.

Figure 2 shows profit as a function of nitrogen application rate for several soil types in the central wheatbelt of Western Australia, as represented in the whole-farm bioeconomic model, MIDAS (Morrison et al. 1986; Kingwell and Pannell 1987). The fertilizer range that provides profit within 5 percent of the optimum is +77 to −51 percent of the optimal fertilizer rate for sandy loam over clay (i.e., any rate between 24 and 88 kg/ha of N gives almost the same profit). Equivalent ranges for the other soils are +75 to −46 percent for shallow sandy loam over clay, and +55 to −42 percent for deep yellow sand. Results broadly similar to this are typical almost everywhere that nitrogen fertilizer is applied (see also Chai et al. 2019).

[Figure 2: *Nitrogen Response Functions*]

The management implications of flat payoff functions are profound. They mean that the farmer has flexibility in choosing the fertilizer rate. If a lower rate would better satisfy another objective (e.g., risk reduction), the farmer can choose that rate with little sacrifice of profit. If a farmer wants to adopt a simple strategy of applying the same nitrogen rate each year, foregoing potentially beneficial adjustments in response to variations in grain price or yield potential, this can be done with little economic sacrifice. If regulators require a moderate reduction in fertilizer rate below the farmer's economic optimum, the cost to the farmer will be small.

A second implication is that the benefits of precision-agriculture technologies that spatially adjust fertilizer rates within a field will usually be small. Before these technologies were imagined, Anderson (1975) argued that "In pursuing … optimal levels of decision variables, precision is pretence and great accuracy is absurdity". Unless the required rate adjustments within a field are very large, a standard rate is likely to fall within the flat range of the payoff function, meaning that a failure to adjust rates does not result in a large loss of profits. That is why economists evaluating this type of precision technology have found that their benefits are not large. Paz et al. (1999), Babcock and Pautsch (1998), Thrikawala et al. (1999), Brennan et al.

(2007) and Robertson et al. (2009) all estimated small or modest benefits from variable-fertilizer-rate technology.

From an environmental perspective, if variable-rate precision technologies are seen as a potential solution to pollution problems, it is unlikely that the adoption of such technologies will be driven by a compelling profit improvement. Conversely, if farmers can be persuaded to reduce their fertilizer rates voluntarily, the profit reduction they have to bear will not be large (provided that the reduction in fertilizer is moderate).

Risk

Maximization of expected profit is a reasonable approximation of the management objective of some farmers (Abadi Ghadim and Pannell 2003), but many are prepared to trade off some expected profit to reduce risk (Binswanger 1980; Antle 1987). If the riskiness of cropping varies for different practices, this would influence decisions about those practices by these “risk averse” farmers. For example, risk commonly varies at different rates of nitrogen fertilizer, and this influences the rate that is preferred.

Risk aversion can vary from mild to extreme, depending on the psychological make-up and the circumstances of different farmers. Economists generally measure risk as the variance or standard deviation of the probability distribution of income. The greater the variance of the outcome for a practice (e.g., a particular application rate of fertilizer), the less attractive it is to risk-averse farmers. The use of variance as the measure of riskiness reflects that there are both downside and upside aspects to risk. Risk-averse farmers give greater weight to the downside, but the upside is not irrelevant to them.

There are various sources of risk that can affect farmers’ decisions about an agricultural practice. For example, consider the decision about the rate of nitrogen fertilizer to apply to a crop. One source of risk is unpredictability of the price at which the crop output will be sold. If this price is subject to risk, then increasing crop yield by applying nitrogen fertilizer will increase the farmer’s overall risk, by increasing the variance of income from the crop. This means that, for risk-averse farmers, greater output-price risk results in a lower optimal fertilizer rate.

Conversely, policies or contracts that reduce output-price risk may increase fertilizer use, depending on what those policies or contracts do to the expected value of output price.

The other main source of risk relevant to nitrogen fertilizer decisions is the riskiness of crop production. The consequence for optimal fertilizer rate of yield risk is less clear-cut than for price risk. It has sometimes been suggested that the application of nitrogen fertilizer reduces farmers' risks, either by reducing their variance of income or by acting as a kind of insurance policy that reduces the probability of bad outcomes (e.g., Sheriff 2005). However, the weight of empirical evidence contradicts this view, both in developing countries (e.g., Mazid and Bailey 1992) and developed countries (Roosen and Hennessy 2003; Rajsic et al. 2009; Monjardino et al. 2015). Therefore, risks associated with both production and output price both tend to result in reduced optimal nitrogen application rates. From this perspective, it follows that policies designed to reduce risk for farmers, such as crop insurance in the United States, are likely to result in increased use of nitrogen fertilizer overall (Horowitz and Lichtenberg 1993), as they allow farmers to adopt more risky nitrogen application strategies without bearing the full consequences of those increased risks. On the other hand, Smith and Goodwin (1996) found that wheat farmers in Kansas who had mutli-risk crop insurance tended to use fewer chemical (including fertilizer) inputs than farmers who did not purchase crop insurance.

Nonetheless, an implication for efforts to encourage adoption of sustainable farming practices is that the relative riskiness of those practices matters. Practices that are perceived to be relatively risky will be less likely to be adopted, especially by those farmers who are more highly risk-averse. This highlights the relevance of understanding how risky a sustainable practice is before setting out to promote it. It may be that those practices that are relatively risky will only be adopted by those farmers who are less concerned about risk (i.e., are "risk neutral"). If these farmers can be identified, there may be scope for targeting efforts to promote these relatively risky practices.

4. Beyond the Farm

Public versus Private Benefits

A feature of practices designed to improve agricultural sustainability is complexity about their private outcomes (for farmers) and public outcomes (for the broader community). Practices are highly variable in this respect. In some cases, the sustainability-related benefits are mainly of interest to the farmer–for example, practices that address soil quality, herbicide resistance, or the quality of local well water for drinking. In other cases, the practices can have impacts on issues that are of strong interest to the broader public–for example, water quality in rivers or the Gulf of Mexico, or CO_2 emissions affecting climate change.

In both cases, decision making by farmers is likely to be mainly based on private outcomes for themselves. For practices in the first category (their sustainability benefits are mainly relevant to farmers), it is appropriate for farmers themselves to make the decisions about whether and how to use the practices. There could be merit in providing farmers with accurate information about the practices, to support their decisions, but if farmers who have accurate information still decide not to adopt a practice, it would be difficult to justify additional interventions to change their decisions.

For practices in the second category (their sustainability benefits are mainly relevant to the general public), the fact that decision making about these practices is dominated by farmers' private interests can be more problematic (Heimlich et al. 1998). There are likely to be cases where farmers decide not to adopt a practice even though the practice would generate large benefits for the public – large enough in theory to outweigh the farmers' private costs. In this case, an intervention to try to better align the two sets of interests may be justified.

In certain cases, the interests of farmers and the broader community are reasonably well aligned–a so-called win-win option. An example would be the adoption of zero-tillage methods, which are profitable for many farmers, whilst also generating benefits that matter to the broader community–potentially both improved water quality and increased carbon sequestration. This case is similar to the scenario illustrated in Figure 1b, at least up to around 60 percent adoption. Note that, given the heterogeneity of farms and farmers, a particular practice may be win-win for some farmers but not others. As a result, the most appropriate intervention may vary between different groups of farmers.

If a practice has public benefits but private costs, one option is to try to influence farmers to change their goals more towards the altruistic generation of public benefits. Experience with this approach (e.g., Lockie and Vanclay 1997) indicates that changing people's personal goals and values is a difficult and long-term undertaking and that even then it is likely to work to only a modest extent. Many farmers around the world have demonstrated that they are willing to make modest financial sacrifices in order to generate public environmental benefits, but expecting farmers (or any other group) to make large financial sacrifices to generate public benefits is likely to be unrealistic.

Another option is to modify the payoffs received for undertaking sustainable practices so that they are attractive to farmers. For example, this might take the form of payments to participating farmers, making access to certain benefits conditional on participation, or establishing regulations to require participation. Clearly, this requires the overseeing organization to have access to sufficient financial resources to make the payments, or sufficient regulatory authority to establish, audit and enforce the regulation. Even if the organization has resources and/or powers, the feasibility of either approach depends on the position of the cost curve (Figures 1a to 1c).

Scaling Up

The earlier discussion about adoption of new practices is couched in terms of the behavior of individual farmers, but to understand environmental impacts we need to think in terms of aggregate behavior across a population of farmers. Figures 1a to 1c illustrate how the heterogeneity of farms and farmers might play out. It might result in easy win-wins (as in Figure 1b), in situations where interventions would be costly and difficult (Figure 1c), or in situations where interventions can make a difference at a reasonable cost (Figure 1a). Figure 1a and 1b reflect that a practice may be adopted by some farmers but not others, or that it may be applied in some areas but not others. The potential to scale up adoption depends on which of these three figures most closely represents the practice.

Private Performance Standards: The Role of Downstream Value Chains

While decisions on how to farm are ultimately taken by farmers, those decisions are not left solely to the discretion of farmers. There are a host of federal, state and local government regulations that influence what inputs (and related farm practices) can be used on what crops, where, when, and how. Some of these public regulations are motivated by public health concerns, others by concerns over farm worker safety or the welfare of farm animals, but many relate to efforts to mitigate the negative environmental consequences of certain farm practices.

Farming takes place in an increasingly interconnected and complex set of supply chains, linking farm fields to food processing, logistic, and wholesale and retail food sales markets. The retail market dimensions of these supply chains are becoming increasingly concentrated. For example, Martinez and Elitzak (2018) estimate that the top 20 companies accounted for 67 percent of U.S. grocery store sales in 2016, well up on their 42 percent market share in 1996.[3] Moreover, many of these large food retailers have corporate responsibility goals that target specific environmental outcomes and now reach well down food supply chains, with direct consequences for farmers. For example, Walmart is "… now asking companies [presumably those who stock their shelves] to commit to reducing [GHG, greenhouse gas] emissions at the farm level" and have "… been working with many of our suppliers over the past five years to support efforts to optimize fertilizer use [on farms] …" (Walmart 2018, p. 37). Similarly, increasing numbers of consumer-packaged-goods companies and related food processing companies have their own sustainability goals, many of which also seek specific environmental outcomes that affect farm practices.

Realizing many of the supply chain sustainability goals and aspirations of food processors, wholesalers and retailers rest squarely on the shoulders of the farmers who are the first link in those supply chains. To the extent that realizing the sustainability goals of these post-farm operators require a change of on-farm production practices, they act as a type of private regulation, adding to the set of public regulations that also influence the decisions farmers

[3] Walmart alone accounted for 26 percent of all on- and off-line U.S. grocery store sales in 2017 (Statista 2018). See also Saitone and Sexton (2017).

must make to participate in a particular supply chain. To the extent that farmers (either via contracts or other means) can choose to whom they sell their product, this places limits on the extent to which the private performance standards of particular downstream participants in these supply chains can influence the choices made by particular farmers. However, perhaps as a reflection of broader consumer concerns regarding the nexus between agriculture and the environment, many of the farm-related environmental objectives of downstream supply chain participants share similar concerns (e.g., reductions in GHG emissions, enhanced water use efficiencies, improved water quality). For similar reasons, perhaps, farmers (and the producer groups that represent their interests) are also beginning to focus their attention on many of these same environmental concerns, not least to sustain their "license to operate" in the eyes of public policy makers and society at large.

Notwithstanding these seemingly similar—but surely uneven and not necessarily convergent (especially in the details)—agricultural-environmental concerns among the different participants in these food supply chains, there are a host of thorny practical, technological, institutional, and economic issues to tackle before environmental concerns (e.g., reduced nitrogen run-off in ground and surface water) can be resolved at scale. The crux of the problem is often bio-economic and involves resolving a fundamental incentive-compatibility problem: specifically, figuring out how to achieve these public-good sustainability goals at scale in a least-cost fashion, and to do that in a way that also sustains the private economic value of farming. For example, food processors, wholesalers or retailers who opt to source only from farmers who adhere to their particular sustainability goals, may find individual growers seeking alternative clients for their produce, or farmers in aggregate may find the goals to be economically unsustainable if they impose additional private costs (over the long run) with no offsetting private benefits to farmers.

5. Mechanisms to Encourage Practice Change

Here we review the pros and cons of a range of potential mechanisms that can be used to try to influence farmers' decision making about adoption of new sustainable agricultural practices.

Before looking at the possible mechanisms, consider Figure 3, which shows, in simplified form, the way that farmer decision making is embedded within a broader system.

[Figure 3: *The indirect and partial influence of mechanism options on environmental consequences*]

The figure indicates how the farmer's management decisions (Box E) are influenced by their economic environment (B), a range of social factors (C), biophysical conditions on the farm (F), and the particular mechanisms used by governments and/or other players. This highlights that the influence of the available mechanisms is likely to be moderated by the influences of the three other factors. The figure also highlights how the choice of mechanism has only an indirect effect on the environmental consequences of interest box G).

Most discussions of the mechanisms to encourage practice change assume that the organization applying the mechanisms would be a government agency (e.g., Vojtech 2010), but here we also assess the relevance of these options to private (post-farm) participants in food supply chains. Within this realm, potential mechanisms include the following.

i. ***Payments from the government to those farmers who qualify by adopting a particular practice or set of practices***

Pros: Can overcome resistance to voluntary adoption by creating a financial incentive to adopt. Payments are most appropriately used where they can prompt a farmer to a change of decisions, from not adopt to adopt.

Cons: Expensive for the funding agency. May crowd out voluntary behaviour (see below). Difficult to know whether the funded actions would have occurred anyway (see discussion of additionality below).

Relevance to a private agribusiness firm: Unlikely to be feasible or worthwhile for a firm to provide financial support to farmers for adopting more sustainable practices.

ii. ***Regulations, backed by penalties for non-compliance***

Pros: Can overcome resistance to voluntary adoption by creating penalties for non-adoption. Less expensive, relative to payments.

Cons: Requires monitoring and enforcement, which are costly. May prompt socio-political resistance from farmers.

Relevance to a private agribusiness firm: Firm is unlikely to have the powers to introduce a regulation. Unlikely to want to impose regulations on suppliers.

iii. ***Provision of information***

Pros: Perhaps a relatively cheap option. Costs include salaries for extension officers who deliver the information and collecting and processing the data required to provide appropriately targeted and relevant information to farmers. Good for engaging farmers. Where lack of information is the main obstacle to adoption, this can be an effective strategy.

Cons: If lack of information is not the main obstacle to adoption, this strategy can support payments or regulation but not be effective on its own.

Relevance to a private agribusiness firm: Be clear about the barriers to adoption for specific practices. In cases where the main barrier is lack of information, this strategy may have a role.

iv. **Market-style approaches. (e.g., a cap and trade approach, a market in environmental offsets)**

Pros: Farmers are prompted to factor in the public benefits of environmental actions when making decisions about whether to do them.

Cons: Relatively complex regulatory system. Requires an ability to introduce a regulation. Experiences so far with this type of system for agricultural water pollution have not been very positive.

Relevance to a private agribusiness firm: If such a system was instituted by government, a firm may be able to assist farmers to operate successfully within the system.

v. ***Investment in research and development to create new sustainable technologies that are more effective and/or more adoptable***

Pros: If win-win technologies can be developed, they largely solve the adoption problem. Can deliver large-scale change at relatively low cost.

Cons: Time lags for research to deliver the required new technologies. Risk that the desired win-win technologies may not be delivered.

Relevance to a private agribusiness firm: Well-targeted investment in development of more sustainable production technologies for farmers may be a worthwhile investment.

The following additional mechanisms are relatively specific to the private sector.

vi. ***Including conditions requiring particular environmental actions within purchase contracts.***

Pros: If the contracted actions are not too onerous, this strategy seems likely to be effective at prompting management change.

Cons: Farmers have choices about who they sell to, so if the conditions are made too onerous, farmers may go elsewhere.

vii. ***Target purchases by post-farm, supply-chain participants to locations where the environmental impacts are likely to be relatively low***

Pros: This strategy side-steps the problem of attempting to influence farmer decision making and instead focuses on decisions that are completely within the control of the agribusiness firm.

Cons: Requires good quality information about environmental impacts from agriculture in different locations. There may be certain constraints on where the firm can purchase agricultural products (e.g., the location of processing facilities).

6. Ensuring That Benefits are Genuine

Technical Issues

In most cases, there is significant uncertainty about the relationship between the use of a particular farming practice and the external environmental benefits, say from reduced water pollution. The farming contexts where any practice can be used are heterogeneous in many respects (soil type, climate, topography, hydrogeology, farming system, etc.) so that it is practically impossible to undertake sufficient research to provide complete confidence about the magnitude of the environmental benefits associated with a given change in farm practice. This is a practical reality that can only ever be partly addressed.

In some cases, a threshold level of change in farm management across the landscape is required before particular benefits are delivered at scale. This is most likely in the case of eutrophication and hypoxic zones. Again, however, accurate quantitative information about where the threshold lies is unlikely to be readily available to a post-farm, private participant in the supply chain (although partnering with public agencies and/or collective pre-commercialization effort by post-farm private participants may generate sufficient information to support the necessary decisions and actions at the farm level).

Time issues contribute to the difficulty. Where the physical system involves long time lags (common with issues involving the movement of groundwater), the difficulty of learning from trials or experiments is heightened. Some adverse environmental events are episodic in nature and/or magnitude (e.g., eutrophication). In these cases, the absence of an adverse event (e.g., excessive farm-level nutrient run-off) in any particular year is insufficient evidence to have confidence that a change in agricultural practice has delivered sustained benefits. Instead, the system must be observed over a sufficiently long time period to determine whether an observed change in frequency (of say eutrophication) is random or likely to be the result of management.

Implementation Issues

When considering the effectiveness of public agri-environmental policies, it is recognized as important to consider whether apparent environmental gains are genuine and will be sustained. To this end, there are four principles that need to be satisfied, as follows. The same four principles are also potentially relevant to a private sector organization that wishes to be certain that its interventions are yielding genuine benefits.

Additionality

This principle is relevant in cases where farmers are rewarded in some way for providing public environmental benefits. The principle is that the reward should only be provided in cases where the environmental benefits would not have been forthcoming in the absence of the scheme (Claassen 2012). In other words, farmers should not be rewarded for undertaking actions that they were going to undertake even without the rewards. Doing so uses up scarce resources that could be used more productively to promote practice change that is actually additional (Claassen et al. 2014). Ignoring this principle runs the risk that a scheme that appears to be generating substantial environmental benefits is not actually doing so–it is simply rewarding good behavior that would have happened anyway.

Figure 1b illustrates a case where there are substantial benefits to farmers for adopting up to the 60 percent level. Rewarding farmers within that 60 percent group for their pro-environmental actions would not actually generate any additional benefits that are attributable to the scheme. Figure 1a illustrates a case where there may be little or no adoption of the practice in the absence of some sort of scheme to support or require the practice.

Assessing additionality is widely recognized as an important requirement (and a considerable challenge) in relation to sequestration of carbon in soils (Thamo and Pannell 2016). However, it is just as relevant to other types of environmental benefits where some sort of reward is used to encourage adoption of the practice.

Leakage

In some cases, an action that is intended to mitigate a pollutant can inadvertently result in other emissions that partly or fully offset the original gains. This has particularly been noted as a problem with carbon sequestration. For example, Montserrat and Sohngen (2009) estimated that in some voluntary offset schemes, up to 90 percent of the claimed emissions 'savings' may have been shifted or 'leaked' to another location. Thamo and Pannell (2016) argued that some forms of leakage could even exceed the original reduction in emissions. The implication here is to be aware of leakage as a risk and to avoid supporting actions where substantial leakage is expected.

Permanence

A particular challenge with soil carbon sequestration is ensuring that the benefits are maintained in the long term. The problem is that, if the new actions that resulted in the extra sequestration are not continued indefinitely, the sequestered carbon will be re-released to the atmosphere. The usual strategy in existing government programs is to require that the new actions be maintained for a certain period (e.g., 25 years or 100 years), and that farmers must pay for the emitted carbon if it is released prior to that time (Thamo and Pannell 2016).[4] A challenge is that this reduces the flexibility of farmers to respond to opportunities (e.g., high market prices) or adverse conditions, so their motivation to participate is diminished.

Crowding Out

Research has shown that providing external incentives (e.g., payments or regulation) to people to provide public goods can sometimes result in them being less willing to provide those good voluntarily in the absence of those incentives (Kits et al. 2014). In other words, externally imposed incentives may crowd out voluntary actions. While the evidence for this effect in agriculture is limited, it does seem likely to be a risk. Possible responses by managers of an incentive scheme could be:

i. ignore the issue and continue to provide the incentive. This might be chosen if the existing level of voluntary action (prior to provision of the incentive) is not high.
ii. avoid the use of incentives, and instead foster increases in voluntary actions without incentives. This might be preferred where it is expected that sufficient change in farmer behavior can be achieved without incentives.
iii. target incentives to situations where the risk of crowding out is judged to be low.

[4] See also Wallander et al. (2018) for an examination of the persistence of zero-till technologies following the removal of government incentives to induce adoption of this technology.

Time Lags in the Process

When establishing targets for environmental benefits resulting from agri-environmental initiatives, it is important to appreciate the time lags that are likely to occur in the process. Time lags can arise in various parts of the process.

i. Once a new farming practice is put in place, there can be a time lag until the environmental improvements occur. Meals et al. (2010), focusing on water quality, break down this time lag into three components: the time required for practices to produce the desired effect, the time required for the effect to be delivered to the water resource, and the time required for the water body to respond to the effect. These lags depend on various factors. For example, the second component (time required for delivery of the effect to the water resource) depends on the distance from the farm field to the water body, and whether the effect is delivered by overland flow (rapid) or via groundwater flow (slow). Lags for the individual elements can range from hours to decades, depending on the situation. For example, Delaware's Inland Bays suffer from nitrates in groundwater, sourced from agricultural fields, poultry operations and from septic-system effluent in the watershed. It is estimated that it takes 50 to 100 years for groundwater to travel from agricultural land in the watershed to the Bays (Meals and Dressing 2008), so any reduction in nitrate leaching on agricultural land would take at least this long before benefits were felt at the Bays. Similarly, Pequea and Mill Creek, Pennsylvania, is affected by nitrogen coming in groundwater from cropland, but the time lag for groundwater to travel to the Creek is 15 to 39 years (Meals and Dressing 2008). In the case of soil carbon, there is a time lag between the establishment of a new land management system and the build-up of carbon in the soil. Typically, it takes decades (e.g., 30-50 years) for a new equilibrium level of soil carbon to be established after a change in management (West et al. 2004).

ii. Once a new farming practice becomes available to farmers, it takes time for farmers to respond and adopt the practice. Different farmers adopt at different times, defining a diffusion curve showing the proportion who have adopted over time. In exceptional cases, most farmers adopt a new practice within about five years, but more commonly the process is much slower than this: often 10-20 years and sometimes longer (e.g. Marsh et al. 2000; Llewellyn and D'Emden 2010).

iii. If the mechanism used to prompt change is investment in research and development to create new sustainable technologies, then there will also be a time lag associated with the research itself. Depending on the complexity of the research and the resources available, research lags of 5 to 15 years are common (Hurley et al. 2016).

Overall, the complete time lags in the delivery of environmental benefits from agricultural lands are often measured in decades, rather than in years. It may be possible to identify and prioritize situations where the lags are likely to be relatively low – e.g., where the majority of nutrient pollution is delivered via surface water rather than groundwater, or where adoption can be accelerated through an incentive-based mechanism.

7. Conclusion

There are likely to be opportunities for private agribusiness firms to influence the decisions of farmers regarding their adoption of sustainable agricultural practices. Such firms have some advantages relative to traditional conservation programs delivered by governments. We see potential in harnessing the private incentives of agribusiness firms to enhance the private incentives of farmers to deliver public environmental benefits. The next two papers in this series will identify specific gaps and opportunities that are worth investigating further in the areas of nutrient pollution in waterways and carbon sequestration in soils.

In this paper, we have provided a range of insights into the delivery of environmental improvements by changes in the management of agricultural lands. We have identified a number of pitfalls, challenges and reality checks for agribusiness firms to be aware of in this space, and suggested a number of ways for prioritizing and targeting efforts. Key insights and messages are summarised in the bulleted list below.

- Farms and farmers are heterogeneous, and so are the various sustainable practices that could be promoted, so the likely adoption of a particular sustainable practice will vary between regions, between farm types, within farms and between farmers with apparently similar farms.

- For the types of sustainable agriculture problems we are focusing on (water quality and carbon sequestration), a fundamental challenge is that farmers' decisions about land management are made mostly on the basis of private benefits and costs to them from the practices, whereas most of the benefits are captured by the general public. Given this situation, it is useful to consider three broad scenarios:

    i. The conservation practice generates sufficient private benefits (or whatever type) for a farmer that she chooses to adopt it even without any additional support or regulation.

    ii. The conservation practice is not sufficiently attractive to prompt voluntary adoption without additional support or regulation, but it is close, and some adoption can be achieved as a result of support or regulation.

    iii. The conservation practice is so unattractive to farmers that no voluntary adoption would occur even with additional support or regulation.

  The greatest opportunity for an initiative to promote sustainable agriculture is in scenario ii. In scenario i intervention is unnecessary, whereas in scenario iii intervention will be unsuccessful.

- For particular sustainable practices, the economic returns to farmers may be affected by flat payoff functions or by considerations of risk.

- There are a number of different potential mechanisms for encouraging farmers to adopt more sustainable practices. They have varying pros and cons and they vary in their likely relevance to an agribusiness firm.

- In some cases, efforts to improve environmental conditions may be compromised, even if it appears superficially to have been successful. It is worth taking care that an initiative generates environmental change that is additional to what would have occurred without the initiative, that avoids problems of leakage, that is permanent (or at least long-lasting) and that doesn’t crowd out voluntary action.

- Time lags between promoting a more sustainable practice and delivering the ultimate environmental improvements are often much longer than commonly appreciated. There are various components to these time lags (e.g. lag until adoption, lag until the practice has the desired effect) and they all vary substantially in duration. It may be possible to identify and target changes that would deliver environmental benefits with relatively short time lags.

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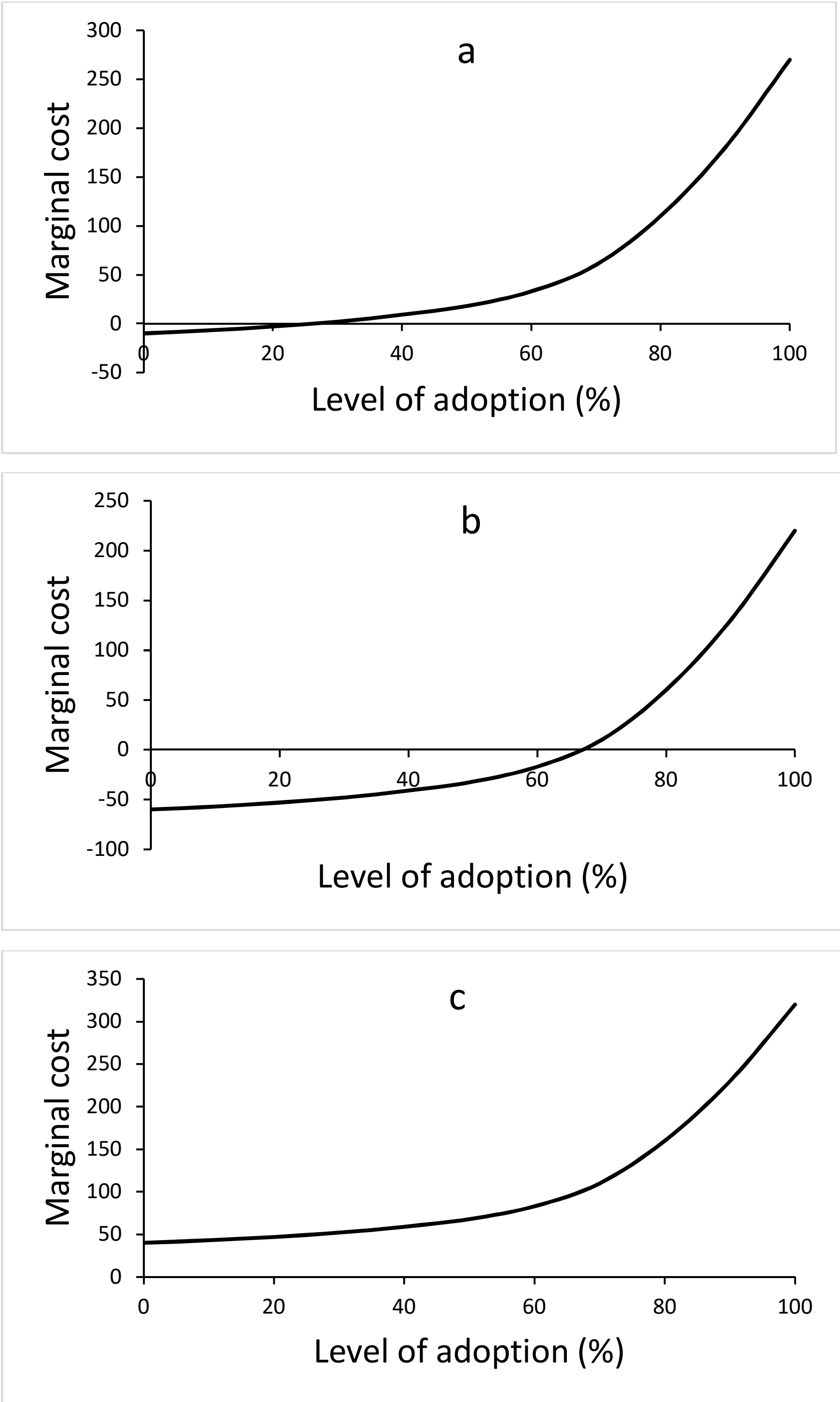
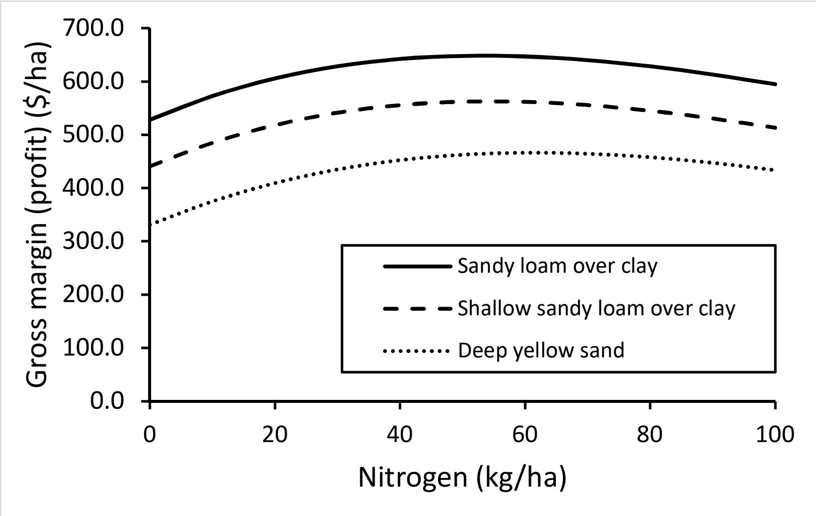
Figure 1: The private marginal cost of adoption by level of adoption (percentage of farming area). a. Slight benefits (negative marginal costs) of adoption up to 25%; b. Benefits of adoption up to 66%; c. Positive costs of adoption at all levels of adoption.



Source: Authors' construction.

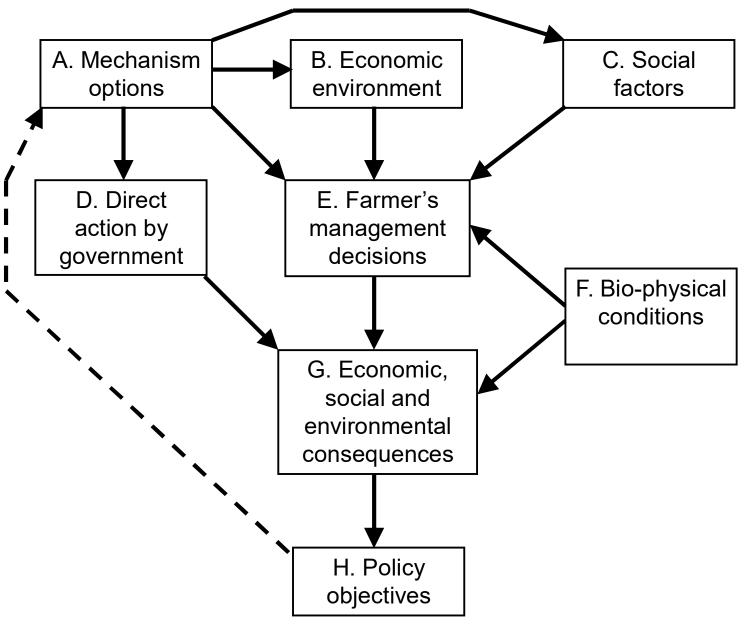
Figure 2. Profit as a function of nitrogen application rate in the central wheatbelt of Western Australia



Source: Morrison et al. (1986).

Notes: Production functions, prices and costs from MIDAS model 2015 version.

Figure 3. The indirect and partial influence of mechanism options on environmental consequences



Source: Authors' construction.